(12)   **EUROPEAN PATENT APPLICATION**

(54) **Method of detecting a leakage of fluid.**

(57) A method of detecting a leakage of fluid is disclosed, in
which a leaking sound, which is produced when the pipe is
broken and propagates through the pipe, is detected by a
couple of acoustic sensors (A, B) mounted to a pipe (C)
through which fluid flows at portions separated from each
other with a proper distance, the amplitudes of a plurality of
different frequency components extracted from the output
signals of the acoustic sensors are obtained and then a
leaking location of fluid in the pipe and a leaking amount of
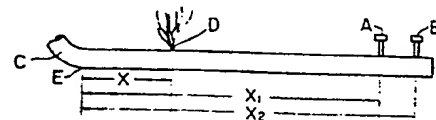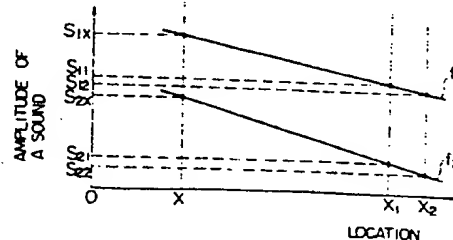fluid are determined on the basis of these amplitudes.

FIG. Ia

FIG. Ib

METHOD OF DETECTING A LEAKAGE OF FLUID

1   The present invention relates to a method of
detecting a leakage of fluid and, more particularly, to
a method of detecting a leakage of fluid by the use of
acoustic sensors.

5   In a nuclear power plant, a chemical plant,
and the like, it is of very importance to prevent at an
early stage an accident of fluid leakage in the piping
system which is caused by a breakdown or crack of the
pipe or the related equipment. If a fluid leaking acci-
10 dent occurs, it is required to immediately find the
location of fluid leakage and an amount of the leaked
fluid in order to ensure a safety.

       There have been proposed various types of
methods of detecting the fluid leakage. A typical
15 example of these methods measures a sound generated when
the fluid leaks. For measuring the sound, piezoelectric
elements are used as acoustic sensors. A location of
the fluid leakage out of a pipe is evaluated on the
basis of the times taken for the sound to reach the
20 acoustic sensors mounted to both ends of the pipe, for
example. When the sound simultaneously reaches the
acoustic sensors, it is judged that the fluid leaks at
the center of the pipe. In this system, however, when a
fluid leakage detecting system fails to detect a leading

1 point, representative of the start of the fluid leakage,

of the sound signals produced from the acoustic sensors,

it is difficult to find the location of the fluid

leakage.

5 Accordingly, an object of the present inven-

tion is to provide a method of reliably detecting a

leaking location of fluid using the output signals from

the acoustic sensors at a proper time point after the

start of the leakage.

10 In the present invention, the amplitudes of a

plurality of different frequency components extracted

from a leaking sound detected by a plurality of acoustic

sensors mounted to spaced positions on a pipe are

obtained and then a leaking location of fluid on the

15 pipe is found on the basis of the amplitudes.

The present invention will be well understood

from the following description of embodiments of the

invention with reference to the accompanying drawings in

which:

20 Fig. 1 schematically illustrates a principle

of detecting a leakage of fluid according to the present

invention;

Fig. 2 shows a graph illustrating a rela-

tionship of leaking locations vs. the amplitudes of a

25 leaking sound;

Fig. 3 shows a block diagram of an apparatus

for detecting the fluid leakage according to the method

1   of the present invention;

Fig. 4 shows a graph illustrating a relationship between a leaking amount of fluid and an amplitude of the leaking sound; and

5   Fig. 5 shows a graph illustrating relationships between an area of a cracked or broken opening and an leaking amount of fluid.

A principle of detecting a leakage of fluid according to the present invention will be described.

10   Acoustic sensors A and B are separately mounted to one end portion of a pipe C through which fluid flows. Assume now that the pipe C is broken at a location D and the fluid leaks therefrom. In most cases, a sound or acoustic wave generated when fluid

15   leaks includes various frequency components exhibiting a continuous spectrum and it is seldom that it includes only a single frequency component. Distances from a point E of one of the ends of the pipe C to a leaking location D and to acoustic sensors A and B are X_1, X_2

20   and X_3, respectively. The acoustic wave of a frequency f_1 has amplitudes S_{11} and S_{12} (logarithmic values) at the locations where the acoustic sensors A and B are positioned. An acoustic wave of a frequency f_2 has amplitudes S_{21} and S_{22} (logarithmic values) at the same

25   locations. The amplitudes (logarithmic values) S_1 and S_2 of the acoustic wave of the frequency f_1 at the leaking location D distanced X from the point E can be

obtained using the distances X_1 and X_2 and the amplitudes S_{11}, S_{12}, S_{21} and S_{22}.

Relationships between the distances X, X_1 and X_2 and the amplitudes S_1, S_{11}, S_{12}, S_{2x}, S_{21} and S_{22} are as illustrated in Fig. 1(b). From these relationships, we have the following equations (1) and (2).

$$(S_{1x}-S_{12})/(S_{11}-S_{12})=(X_2-X)/(X_2-X_1) \quad \ldots\ldots (1)$$

$$(S_{2x}-S_{22})/(S_{21}-S_{22})=(X_2-X)/(X_2-X_1) \quad \ldots\ldots (2)$$

Three unknown quantities are contained in the above equations (1) and (2). By introducing an equation (3) into the above equations, the unknown quantities S_{2x} and X are expressed by equations (4) and (5).

$$S_{1x}/S_{2x}=k \text{ (constant)} \quad \ldots\ldots (3)$$

$$S_{2x}=(S_{12}-\alpha S_{22})/(k-\alpha) \quad \ldots\ldots (4)$$

$$X=X_2-\beta(X_2-X_1)/\gamma \quad \ldots\ldots (5)$$

where α, β and γ are given by the following equations (6) to (8).

$$\alpha=(S_{11}-S_{12})/(S_{21}-S_{22}) \quad \ldots\ldots (6)$$

$$\beta=S_{12}-kS_{22} \quad \ldots\ldots (7)$$

$$\gamma=(S_{21}-S_{22})(k-\alpha) \quad \ldots\ldots (8)$$

where k is a constant experimentally determined. The relationship between an amount of the fluid leakage Q and the amplitude S_{1x} or S_{2x} of the given frequency component detected at the leaking location D is given by a known function $Q = F(S_{1x})$ or $Q = F(S_{2x})$.

In this way, the unknown quantities X, S_{1x} and S_{2x} are obtained. With denotation of ρ for an attenuation

1   factor of a fluid leaking sound when propagating through

the pipe C, equations (9) and (10) hold

$$S_{1x} - \rho_1(X_1 - X) = S_{11} \qquad \cdots\cdots (9)$$

$$S_{2x} - \rho_2(X_1 - X) = S_{21} \qquad \cdots\cdots (10)$$

5   where ρ_1: Attenuation factor for the frequency f_1

ρ_2: Attenuation factor for the frequnecy f_2.

Therefore, from the equations (9) and (10), the unknown

quantities S_{2x} and X are given

$$S_{2x} = (S_{11} - \rho_1 S_{21}/\rho_2)/(k - \rho_1/\rho_2) \qquad \cdots\cdots (11)$$

10   $$X = X_1 + (k S_{21} - S_{11})/\{\rho_2(k - \rho_1/\rho_2)\} \qquad \cdots\cdots (12)$$

In this way, the leaking location D and the

leaking amount Q of the fluid are obtained.

The relationship between leaking location X in

Fig. 1(b) and an amplitude S of 100 KHz frequency com-

15   ponent in the leaking sound, which were actually

measured of a steel pipe, is shown by a graph of Fig. 2.

A method of detecting a leakage of fluid based

on the above principle will be described with respect to

an embodiment applied to a boiling-water nuclear power

20   generating plant as shown in Fig. 3. In the power

generating plant, cooling water is evaporated in a reac-

tor core 2 of a reactor pressure vessel 1. The vapor is

discharged from the reactor pressure vessel 1 to a main

steam pipe 3 and then is led to a turbine (not shown).

25   The vapor discharged from the turbine is condensed into

water, i.e. cooling water, in a condenser (not shown).

The cooling water is returned through a water feed pipe

1 4 to the reactor pressure vessel 1. The cooling water

   therein is led to the reactor core 2 via a recirculating

   system. The recirculating system is comprised of a

   recirculating pipe 5 connected to the reactor pressure

5 vessel 1 and a recirculating pump 6 provided in the

   recirculating pipe 5. A control rod 7 for controlling a

   reactor output power is inserted into the reactor core

   2. The control rod 7 is coupled with a control rod

   driver 8.

10   The sensors 9 and 10 are mounted to the recir-

   culating pipe 5 downstream of the recirculating pump 6

   and slightly separated from the recirculating pipe 5.

   The acoustic sensors 9 and 10 detect a leaking sound

   which is generated due to the breakage of the pipe and

15 propagates through the pipe. The output signals from

   the acoustic sensors 9 and 10 are applied to amplitude

   detectors 11 and 12. Each detector detects an amplitude

   of the signal output from the corresponding sensor and

   compares it, by a comparator contained therein, with a

20 predetermined value corresponding to the amplitude of a

   leaking sound produced when the breakage of the pipe is

   minimum. When the amplitude of the output signal from

   the acoustic sensor exceeds the predetermined value, it

   is judged that the fluid leakage takes place in the

25 recirculating pipe 5. When the amplitude detectors 11

   and 12 judge that the amplitudes of the output signals

   from the acoustic sensors are larger than the respective

1 predetermined values, the amplitude detector 11 produces

a signal for closing a switch 13 and the amplitude

detector 12 produces a signal for closing a switch 14.

Upon receipt of these signals, the switches 11 and 12

5 are closed. So long as the signals are not produced

from the amplitude detectors 11 and 12, respectively,

the switches 13 and 14 are in an open state. As the

result of closing the switches 13 and 14, the output

signals from the sensors 9 and 10 are applied to band-

10 pass filters 15 and 16, respectively. The band-pass

filter 15 includes separate filter units for producing

output signals representative of the amplitudes S_{11} and

S_{12}, respectively, of the frequency component f_1 in the

respective signals from the sensors 9 and 10. The band-

15 pass filter 16 likewise produces output signals repre-

sentative of the amplitudes of the frequency component

f_2 in the signals from the sensors. The amplitude

signals S_{11}, S_{12}, S_{21} and S_{22} from the band-pass filters

are applied to an arithmetic unit 17. Upon receipt of

20 these signals, the arithmetic unit 17 calculates the

amplitudes S_{1x} and S_{2x} and the distance X from the

reference position E to the leak position D according to

the equations (9), (11) and (12). The attenuation fac-

tors ρ_1 and ρ_2 are dependent on the material and shape

25 of the pipe. Accordingly, the attenuation factors

ρ_1 and ρ_2 can previously be determined by an experimen-

tal study using a scale-down model of the pipe system

1   actually used in nuclear power plant. The attenuation

     factors thus obtained are stored in a memory of the

     arithmetic unit 17.

          The arithmetic unit 17 produces signals repre-

5   senting the amplitude S_{1x} and the distance X. The

     signal of the amplitude S_{1x} is applied to a function

     generator 18. The function generator 18 produces an

     amount of the fluid leakage Q corresponding to the

     amplitude S_{1x} applied thereto according to a rela-

10   tionship between them as shown in Fig. 4. The amount of

     the fluid leakage Q is applied to a comparator 19 and an

     operation unit 20. The comparator 19 compares the

     amount of the fluid leakage Q with its set value. When

     the amount of the fluid leakage Q is larger than the set

15   value, the cooling water in the reactor pressure vessel

     1 of the nuclear reactor is possible to rapidly reduce,

     thereby lowering the level of the cooling water,

     resulting in the fuel assembly exposing out of the

     cooling water, and the boiling-water nuclear reactor

20   being in a dangerous state. Accordingly, when the

     amount of the fluid leakage Q exceeds the set value, the

     comparator 19 produces a scram signal which is supplied

     to a controller 21. Under control of the scram signal,

     the controller 21 drives the control rod driver 8 to

25   rapidly insert the control rod 7 into the reactor core 2

     so as to scram the nuclear reactor.

          The arithmetic unit 20, when receiving the

1 amount of the fluid leakage Q, operates to calculate an

opening area of a broken part of the pipe, as a function

of a differential pressure to be described later. For

measuring the differential pressure, a pressure gauge

5 22, a pressure gauge 24 and a differential pressure

gauge 25 are provided. The pressure gauge 22 measures

an internal pressure P_1 of the recirculating pipe 5.

The pressure gauge 24 measures an internal pressure P_2

in the nuclear reactor container 23 enclosing the reac-

10 tor pressure vessel 1 containing the recirculating pipe

5. The differential pressure is obtained by the dif-

ferential pressure gauge 25, as a difference between P_1

and P_2 and applied to an arithmetic unit 20. Upon

receipt of the amount of the fluid leakage Q and the

15 differential pressure, the arithmetic unit 20 calculates

an opening area of the broken part of the pipe,

according to the relationship as shown in Fig. 5.

The distance X and the opening area produced

from the arithmetic units 17 and 20 are displayed by a

20 display 26.

As described above, the embodiment obtains a

fluid leaking location, using the amplitude information

for two frequency components of the leaking sound

received by two acoustic sensors separately mounted to

25 the pipe at proper different locations of the pipe.

Further, it obtains the amount of the fluid leakage

using the amplitude information for the two frequency

1   components and the amplitude information at the leaking

     locations. Further, the opening area of the broken part

     of the pipe may be obtained. It is noted that even when

     failing to catch the output signal representative of a

5   fluid leakage start point from the sensor, the leak

     location, the amount of the leaking fluid, and the

     opening area of the broken part of the pipe can reliably

     be obtained using a stationary fluid leaking sound after

     the fluid leaks. Further, the present embodiment can

10   detect a leakage of fluid occuring in the pipe at a por-

     tion between the acoustic sensors or at other portions.

     This feature remarkably reduces the number of the

     acoustic sensors to be mounted to the pipe.

          It is evident that the present invention is

15   applicable to any suitable plants other than the nuclear

     power plant. Additionally, the present invention can

     reliably detect the leaking location of the pipe even

     when the fluid leak detecting system fails to catch the

     leading point of the leak sound produced at the start of

20   the fluid leak.

WHAT IS CLAIMED IS:

1.   A method of detecting a leakage of fluid
comprising the steps of:

         detecting a leaking sound of fluid by a plura-
lity of acoustic sensors (9, 10) separately mounted to a
pipe (5) through which fluid flows;

         obtaining amplitudes of a plurality of dif-
ferent frequency components extracted from the output
signals from said acoustic sensors; and

         determining a leaking location of fluid of
said pipe on the basis of said amplitudes.

2.   A method of detecting a leakage of fluid
according to claim 1, further comprising the step of
determining an amount of leaking fluid on the basis of
said amplitudes.

3.   A method of detecting a leakage of fluid
according to claim 2, further comprising the step of
determining an opening area of a broken part of said
pipe on the basis of a differential pressure between a
first pressure in said pipe and a second pressure out-
side said pipe, and the amount of the leaking fluid.

4.   A method of detecting a leakage of fluid
comprising the steps of:

         detecting a leaking sound of fluid by a plura-
lity of acoustic sensors separately mounted to a pipe
through which fluid flows in a plant;

         obtaining amplitudes of a plurality of

different frequency components extracted from the output signals from said acoustic sensors; and

determining a leaking location of fluid of said pipe on the basis of said amplitudes.

5.   A method of detecting a leakage of fluid according to claim 4, further comprising the step of determining an amount of leaking fluid on the basis of said amplitudes.

6.   A method of detecting a leakage of fluid according to claim 5, further comprising the step of stopping the operation of said plant wherein when said amount of leaking fluid exceeds a set value.

7.   A method of detecting a leakage of fluid according to claim 5, wherein said plant is a nuclear reactor plant, and further comprising the step of scraming said nuclear reactor plant when said amount of a leaking fluid exceeds a set value.
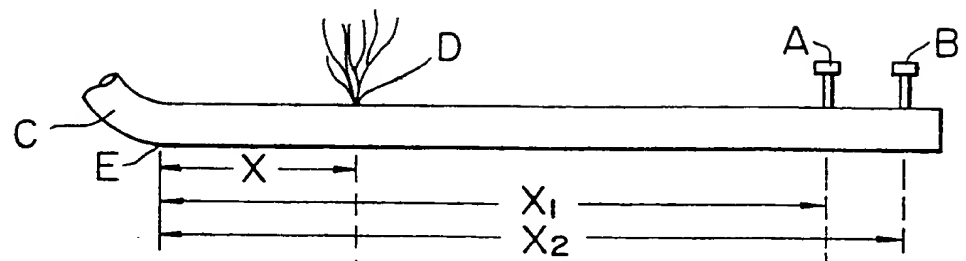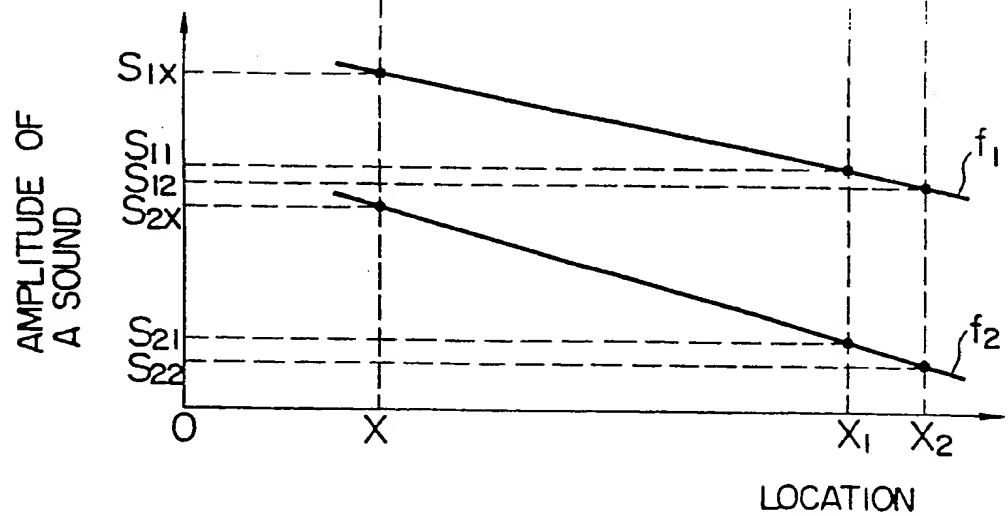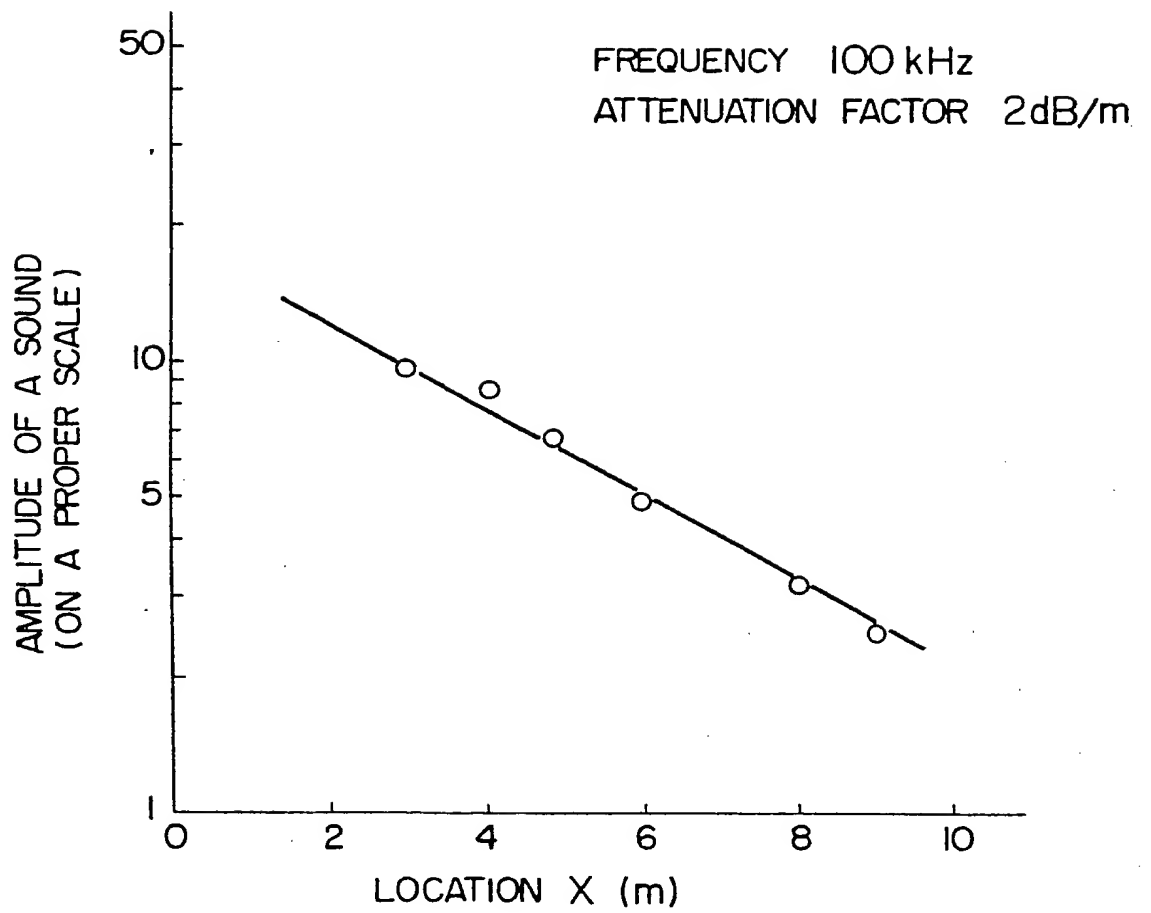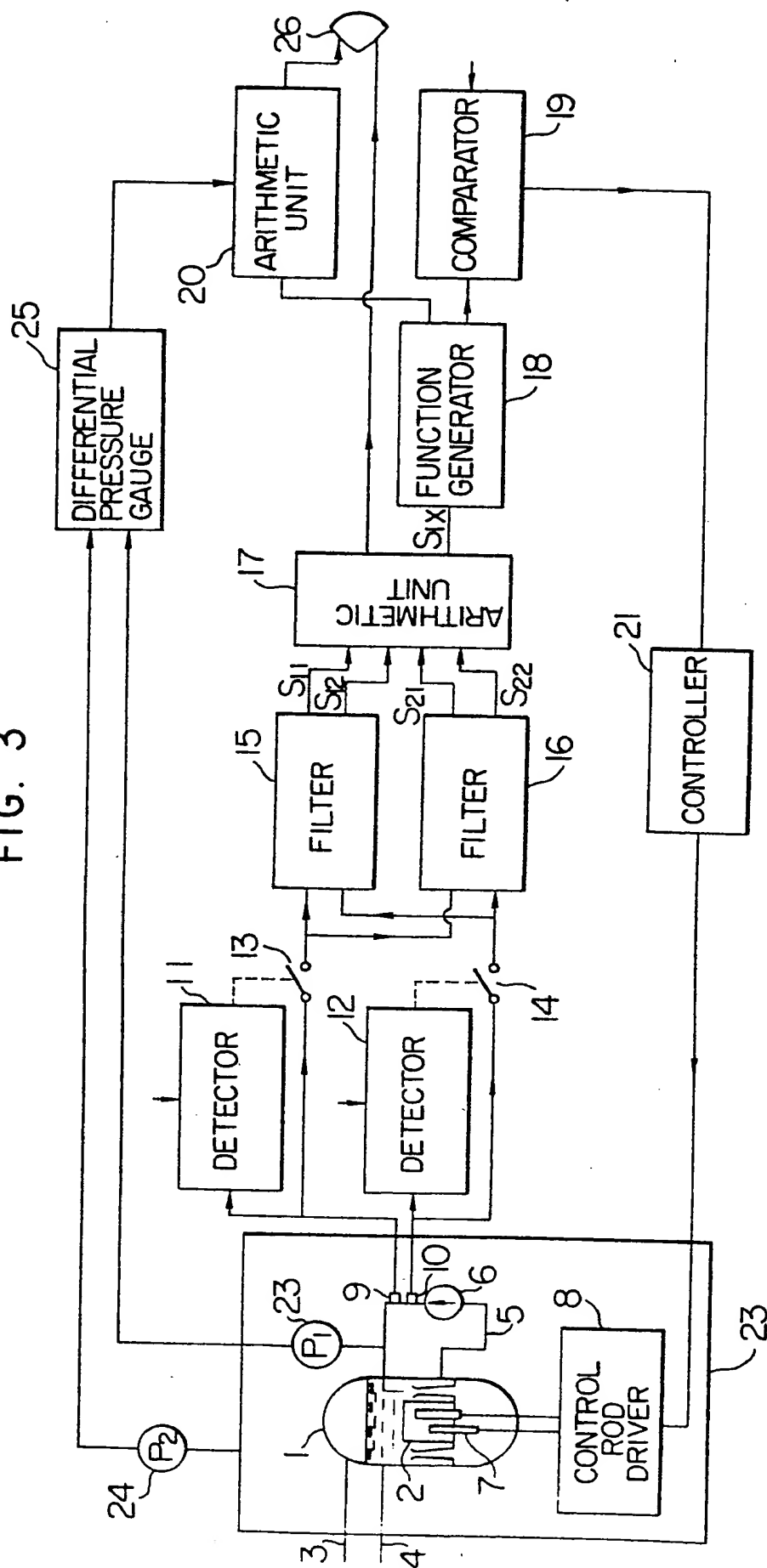
FIG. 1a

FIG. 1b

FIG. 2

FREQUENCY   100 kHz
ATTENUATION FACTOR   2dB/m

FIG. 3

FIG. 4

FIG. 5